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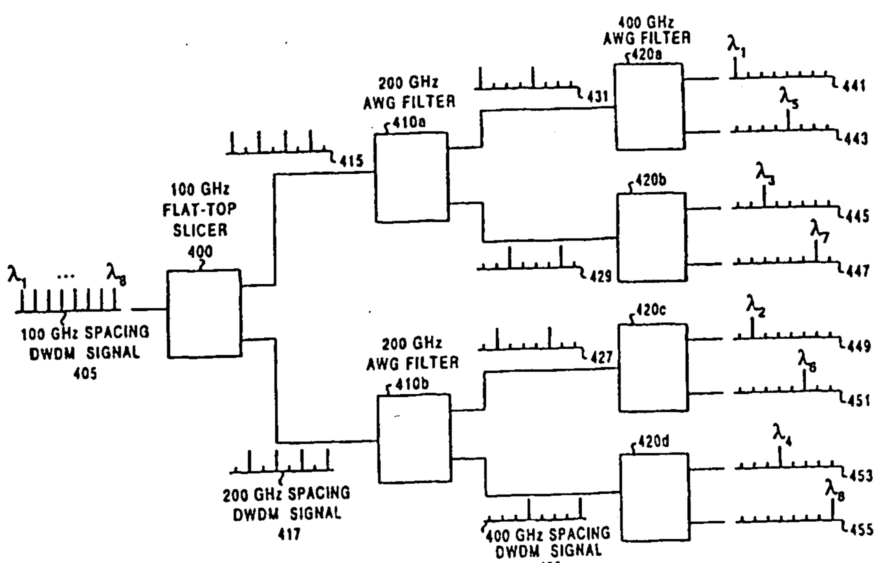

(57) Abstract

A wavelength division multiplexing/demultiplexing device is presented utilizing a polarization-based filter to obtain a flat-top filter response which can be utilized to create a flat-top slicer (400) which separates out odd and even wavelengths, or upper and lower channels of an input signal. The polarization-based filter provides superior peak flatness and isolation for narrow channel spacings over what can be obtained in traditional interferometric devices. The flat-top slicer can be used as the first stage (110) of a cascade of WDM devices in which following stages (140, 150) can be based on polarization-based filters or traditional interferometric WDM devices, which are adequate due to the increased channel spacing obtained in the first stage of the cascade.

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METHOD AND APPARATUS FOR WAVELENGTH MULTIPLEXING / DEMULTIPLEXING

BACKGROUND OF THE INVENTION

Field of the Invention. The present invention relates generally to the field of optical communications. More specifically, the present invention discloses a method and apparatus for wavelength multiplexing and demultiplexing.

Background of the Invention. Wavelength division multiplexing is a commonly used technique that allows the transport of multiple optical signals, each at a slightly different wavelength, on an optical fiber. The ability to carry multiple signals on a single fiber allows that fiber to carry a tremendous amount of traffic, including data, voice, and even digital video signals. As an example, the use of wavelength division multiplexing permits a long distance telephone company to carry thousands or even millions of phone conversations on one fiber. By using wavelength division multiplexing it is possible to effectively use the fiber at multiple wavelengths, as opposed to the costly process of installing additional fibers.

In wavelength division multiplexing techniques, multiple wavelengths can be carried within a specified bandwidth. It is advantageous to carry as many wavelengths as possible in that bandwidth. International Telecommunications Union (ITU) Draft Recommendation G.mcs, incorporated herein by reference, proposes a frequency grid which specifies various channel spacings including

100GHz and 200GHz. It would be advantageous to obtain 50 GHz spacing. Separating and combining wavelengths with these close spacings requires optical components which have high peak transmission at the specified wavelengths and which can provide good isolation between separated wavelengths.

One technique which has been developed to accomplish the demultiplexing of closely spaced wavelengths is to cascade a series of wavelength division demultiplexing devices, each device having different wavelength separating characteristics. A typical application involves cascading an interferometric device such as an arrayed waveguide device having a narrow spacing of transmission peaks (e.g., 50 GHz) with a second interferometric device which has a coarser spacing and correspondingly broader transmission peaks (e.g., 100 GHz spacing). The cascade of devices provides the separation of wavelengths by subdividing the wavelengths once in the first device, typically into a set of odd and even channels, and then separating wavelengths in the subsets in following devices in the cascade.

Arrayed waveguide (AWG), fused biconical taper (FBT), fiber Bragg grating (FBG), diffraction grating, and other interferometric wavelength demultiplexing devices can be constructed to have the appropriate characteristics for the first or second stage devices in the cascade. However, traditional interferometric devices have the characteristic that as the spacing of the channels is decreased, the transmission peaks become narrower, and are less flat over the wavelength region in the immediate vicinity of each peak than a device with wider channel spacings. As a result, when using a traditional device in the first stage of a cascade, the transmission peaks may not have a high degree of flatness, and any drift or offset of a wavelength from its specified value may result in significant attenuation of that wavelength. In addition, the isolation between

wavelengths is frequently unsuitable with conventional interferometric devices and can result in unacceptable crosstalk between channels. With increasing numbers of wavelengths and the close wavelength spacing which is utilized in dense wavelength division multiplexing systems, attenuation and crosstalk must be closely controlled to meet the system requirements and maintain reliable operations. As an example, 40 or 80 wavelengths can be generated using controllable wavelength lasers, with transmission signals modulated onto each laser. It is desirable to be able to multiplex and demultiplex these channels onto one single optical fiber. Although the lasers can be controlled and the wavelengths stabilized to prevent one channel from drifting into another, there is always some wavelength drift which will occur.

In a cascade architecture, the first stage of demultiplexing, or the last stage of multiplexing are where good peak flatness and high isolation are required in order to allow the separation/combining of closely spaced wavelengths.

For the foregoing reasons, there is a need for a wavelength division multiplexing/demultiplexing device which tolerates wavelength drift, maintains a high degree of isolation between channels, and is able to separate/combine large numbers of wavelengths.

SUMMARY OF THE INVENTION

The present invention encompasses a method and apparatus for wavelength division multiplexing/demultiplexing in which a cascade is formed between a polarization-based wavelength multiplexing/demultiplexing device and a second wavelength multiplexing/demultiplexing device. The polarization-based wavelength division multiplexing/demultiplexing device has transmission peaks which are substantially flat as a result of the characteristics of a polarization-based filter which is part of the device. In addition, the polarization filter provides a high degree of isolation between adjacent channels. The output of the polarization-based wavelength division multiplexing/demultiplexing device is received by a second stage of wavelength multiplexing devices which further separates the wavelengths. One advantage of the present invention is that the polarization-based wavelength multiplexing/demultiplexing device has good peak flatness and low crosstalk, and permits separation of closely spaced wavelengths (e.g., 50 GHz spacing). The subsequent devices in the cascade can be based on a number of technologies including arrayed waveguide technology, fused biconical taper technology, diffraction grating technology, fiber Bragg grating technology, interference filter, or can also be polarization-based devices. The subsequent devices are used to separate channels which have been formed into subgroups by the polarization-based wavelength multiplexing/demultiplexing device.

In a preferred embodiment the polarization-based wavelength multiplexer/demultiplexer creates two subsets, one subset containing the odd channels from the input channels, the other subset containing the even channels from the input channels. The second device further separates the wavelengths in the first and second subsets, resulting

in a wavelength spacing at the output which is 2N times the wavelength spacing at the input of the polarization-based wavelength multiplexer/demultiplexer. In a preferred embodiment the second stage performs the subsequent demultiplexing operations. In an alternate embodiment multiple stages are used in the cascade to further separate the wavelengths and produce a single channel at the final output.

In an alternate embodiment, the polarization-based wavelength multiplexer/demultiplexer separates an upper band from a lower band. Subsequent stages are used to further separate the channels.

When a large number of channels are present, the polarization-based multiplexer/demultiplexer can be utilized to separate the channels into groups, and subsequent stages can be used to continue the multiplexing/demultiplexing process. In a preferred embodiment, when used as a demultiplexer, the present invention separates an input signal into two groups of channels, the even channels and the odd channels. A subsequent stage based on arrayed waveguide (AWG) technology performs the final multiplexing, resulting in individual channels at the output.

In a preferred embodiment the polarization-based wavelength division multiplexing/demultiplexing device is based on a polarization routing device which receives an optical signal carrying multiple channels at various wavelengths, separates the signal into vertical and horizontal polarizations, converts one of the polarizations to be identical to the other polarization, and performs filtering based on the wavelength of the signal, with the polarization of the output being dependent on the wavelength. A polarization routing stage routes light to a particular output depending on its polarization, and a polarization conversion and recombination stage combines the polarizations at each output to form an output signal.

In a preferred embodiment the polarization filter is composed of calcite birefringent crystal plates. A polarization mode dispersion compensator can be utilized in the device to reduce the polarization dispersion.

In the present invention the transmission function obtained in the first stage of a cascade demultiplexer has Fourier components such that the transmission function is substantially flatter and has steeper roll-off from the peaks than the transmission function in the second or subsequent stages. The additional Fourier components in the first stage result in a substantially square transfer function as compared to the second stage transfer function. In a preferred embodiment, the first stage transfer function is realized through the use of a polarization filter, which enables angle to be used as a variable in addition to path length, permitting the incorporation of the additional Fourier components necessary to make a square wave transfer function.

One advantage of the present invention is that it allows the use of low cost interferometric devices in second and higher stages of a wavelength division multiplexing/demultiplexing device while achieving good flatness and low crosstalk through the use of a polarization-based first stage.

In a preferred embodiment a large number of channels (e.g., 40 or 80) with 100 GHz spacing enter the device and are separated according to even and odd channels by a polarization-based first stage device with a spacing of 200 GHz. The second stage device is an arrayed waveguide device which separates the channels into individual channels which appear on the outputs, and which can be individually received by a telecommunications receiving device which is not wavelength selective.

These and other features and objects of the invention will be more fully understood from the following detailed description of the

preferred embodiments which should be read in light of the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings illustrate the embodiments of the present invention and, together with the description, serve to explain the principles of the invention:

FIG. 1 illustrates the concept of wavelength slicing and cascading of WDM filters.

FIG. 2 illustrates the flat-top slicer spectral response.

FIG. 3 illustrates a flat-top slicer followed by two stages of filters.

FIG. 4 illustrates a configuration for a wavelength slicer.

FIGS. 5a and 5b illustrate the spectral response for flat-top spectral slicers.

FIG. 6 illustrates a spectral response for a polarization-based wavelength separation device.

DETAILED DESCRIPTION OF THE INVENTION

In describing a preferred embodiment of the invention illustrated in the drawings, specific terminology will be used for the sake of clarity. However, the invention is not intended to be limited to the specific terms so selected, and it is to be understood that each specific term includes all technical equivalents which operate in a similar manner to accomplish a similar purpose.

When used herein, the term multiplexer/demultiplexer refers to a device which can be used to either combine or separate wavelengths. However, such a definition does not preclude the use of the device for one function only. In addition, nonreciprocal elements can be added, precluding use of the device for one of the functions of multiplexing or demultiplexing, although the features and functionality of multiplexer/demultiplexer remain the same in the direction of use.

When used in a cascade, the term first stage refers to the first stage of the cascade in a demultiplexing configuration, where closely spaced wavelengths enter the system and are separated. When used in a multiplexing configuration, the last stage of the system performs the final multiplexing of the wavelengths, and corresponds to the first stage of the demultiplexer. When used herein the term first stage refers to the first stage in a demultiplexing operation and to the last stage in a multiplexing operation. The term flat-top slicer refers to a wavelength multiplexing/demultiplexing device with a substantially square input port to output port transmission function.

With reference to the drawings, in general, and FIGS. 1 through 6 in particular, the apparatus of the present invention is disclosed.

FIG. 1 illustrates a cascade of wavelength division multiplexers (WDMs). A number of channels at wavelengths λ_1 through λ_n appear

at input port A 100 which is part of WDM 1 110. In a preferred embodiment WDM 1 110 separates out a first subset of odd numbered wavelengths which include λ_1 through λ_{n-1} which appear on output port B_1 120. Similarly, WDM 1 110 separates out a second subset of even numbered wavelengths which include λ_2 through λ_n which appear on port B_2 130. In an alternate embodiment the first set of wavelengths includes λ_1 through $\lambda_{n/2}$ and the second set of wavelengths includes $\lambda_{[(n/2)+1]}$ through λ_n.

Port B_1 120 is coupled to WDM 2-1 140 which further separates out wavelength λ_1 which appears at port 160, wavelength λ_3 which appears at port 161, and remaining odd wavelengths through λ_{n-1} which appears on port 169. Similarly, Port B_2 130 is coupled to WDM 2-2 150 which further separates out wavelength λ_2 which appears at port 170, wavelength λ_4 which appears at port 171, and remaining even wavelengths through λ_n which appears on port 179.

In an alternate embodiment the lower half of the wavelengths at input port A 100 are separated by WDM 2-1 140 and the upper half of the wavelengths at input port A 100 are separated by WDM 2-2 150.

Traditional interferometric devices suffer from the problem that as the transmission peak spacing is decreased, the flatness at the top of the transmission peak is reduced, due to the fact that the bandwidth at the top of the peak is reduced as a consequence of having more closely spaced peaks. While many WDM systems require that the variations in transmission be less than 0.5 dB over 0.3 nm or better, it is not generally possible to obtain such flatness using traditional interferometric devices. As a result, if there is any wavelength drift of any of the input signals, there will be subsequent attenuation due to the fact that the signal is no longer at a transmission peak. In addition, the isolation between signals at

adjacent wavelengths can be unacceptable due to the fact that the attenuation at the bottom of the transmission curve is not low enough over a wide enough wavelength region. This reduced isolation can result in unacceptable crosstalk between channels.

The present invention avoids the aforementioned problems through the use of a flat-top slicer as WDM 1 110. The flat-top slicer provides a wavelength separating function which has adequate flatness and isolation. The transmission function for the flat-top slicer is illustrated in FIG. 2. Solid line 300 represents the transmission from port A 100 to port B_1 120 in a flat-top slicer while dotted line 310 represents the transmission from port A 100 to port B_2 130 in a flat top slicer.

In a preferred embodiment the flat-top slicer is realized based on a polarization-based wavelength multiplexing/demultiplexing device containing a polarization filter. Polarization filters provide the ability to obtain a tailored optical response as a function of wavelength and can provide superior performance over non-polarization based filters because they permit the use of polarization angle as well as path length (thickness) as a variable in creating the filter response. Polarization filters are typically embedded in an optical system which subsequently recombines the polarizations to produce a polarization independent device. Polarization filters are well understood by those skilled in the art, and are described in published books and literature, including the book by A. Yariv and P. Yeh entitled "Optical waves in crystals," which is incorporated herein by reference.

For example, the polarization filter can be composed of a plurality of birefringent elements, such as birefringent crystal plates (e.g., calcite or other birefringent crystalline materials). The polarization filter could also be made using a polarization fiber. A polarization mode dispersion compensator can be utilized in the device to reduce the polarization dispersion.

FIG. 4 illustrates a polarization-based wavelength multiplexing/demultiplexing device which can be used to realize the present invention. When used herein, the term flat-top slicer refers to such a polarization-based wavelength multiplexing/demultiplexing device or its equivalents. The flat-top slicer is employed as WDM-1 110. This device has been described in detail in U.S. Patent Application U.S. Patent Application Serial No. 09/156,211 entitled "Programmable Optical Add/Drop Multiplexer," filed September 17, 1998.

As shown in FIG. 4, an optical signal carrying eight optical channels 512 enters the system and is decomposed in a birefringent element 500 into two orthogonal polarization components, namely vertical and horizontal polarizations 514a and 514b respectively. One of the light paths 514b is passed through a polarization converter 516 such that both light paths have the same state of polarization (vertical or horizontal). These two beams then pass through a polarization filter 518 such that the odd-channels are coded with (output in) horizontal polarization and the even channels are coded with vertical polarization. These two polarizations are then separated by the following polarization beam separator (PBS), 524a, b which passes the horizontal polarization 526a, c straight through the PBS and deflects the vertical polarization 526b, d by 90°. Because the odd and even channels reside within the two polarizations respectively, they are spatially separated after the PBS.

In an alternate embodiment polarization filter 518 can be constructed to polarize code lower and higher channels differently, resulting in routing according to the channel position in the upper or lower parts of the input band.

Referring to FIG. 4 polarization converters 530a, 530b are used to convert polarizations by 90°, and birefringent elements 540a and

540b recombine the polarizations to produce odd numbered wavelengths at output port 550a and even numbered wavelengths at output port 550b. In a preferred embodiment polarization converters 530a, 530b are half wave plates.

FIG. 5A illustrates the transmission characteristics of polarization filter 518 for light with a first (e.g., vertical) polarization, and FIG. 5B illustrates transmission through the filter 518 of this embodiment for a second (e.g., horizontal) polarization. The transmission envelopes are shaped to provide sufficient width, as depicted, to tolerate expected wavelength drift while still being sufficiently narrow to achieve the necessary discrimination with respect to other channels. In one embodiment, suitable filters may be made as described in U.S. Patent 5,694,233 entitled "Switchable Wavelength Router," or U.S. Patent Application 09/020,706 entitled "Temperature Insensitive Polarization Filter," both incorporated herein by reference.

A polarization mode dispersion compensator 560 can be used as illustrated in FIG. 4. Polarization mode dispersion is defined as the difference in the propagation time between the two orthogonal polarization components. In a polarization-based routing device, different propagation delays may occur between two routes. As illustrated in FIG. 4, the propagation times resulting from the propagation path in the through port (output port 550a) are equal for both polarizations. On the other port (output port 550b) one of the polarization beams 526d passes through two half-wave plates, while the other 526b does not. To minimize the difference in propagation times for these two beams, a polarization mode dispersion (PMD) compensator 560 is inserted into path 526b. In a preferred embodiment, an isotropic glass plate is used to realize PMD 560. Alternate materials can be used to realize PMD compensator 560 and are known to those skilled in the art.

FIG. 6 illustrates in greater detail the transmission characteristics of a flat-top slicer when used with a channel spacing of 100 GHz (approximately 8 nm). At the transmission peak a flatness of 0.5 dB over a range of 0.3 nm can be obtained using a polarization filter in a polarization-based routing device. In terms of isolation, the transmission minimum can be 30 dB lower than the transmission value, and can remain that low over a 0.24 nm range between wavelength peaks. As a result, the flat-top slicer can tolerate wavelength drift and maintains low attenuation (high transmission) and low co-channel interference (low crosstalk). The solid portion 617 of the curve in FIG. 6 represents the transmission function from port A–B_1, while the dotted portion 627 represents the transmission function between ports A-B_2.

FIG. 3 illustrates an industrial application of the present invention in which a 100 GHz spaced dense wavelength division multiplexing (DWDM) signal 405 enters a 100 GHz flat-top slicer 400, which produces an odd-channel 200 GHz spacing DWDM signal 415 and an even channel 200 GHz spacing signal 417. Two 200 GHz filters 410a, 410b are used to produce a 400 GHz spaced signal carrying wavelengths λ_1 and λ_5 431, a signal carrying wavelengths λ_3 and λ_7 429, a signal carrying wavelengths λ_2 and λ_6 427, and a signal carrying wavelengths λ_4 and λ_8 425. A third stage of filters 420a-d are used to produce the individual channels λ_1 through λ_8 on outputs 441, 449, 445, 453, 443, 451, 447 and 455 respectively. By using a flat-top slicer as the first stage for wavelength separation, good isolation and tolerance to wavelength drift is obtained. Subsequent stages can be based on alternate technologies, since the wavelengths have been separated by one channel spacing in flat-top slicer 400. In an alternate embodiment, the subsequent stages can be based on flat-top slicers using polarization-based filters in a polarization

multiplexing/demultiplexing device. In yet another embodiment, the second and third stages are combined in one device, which can be based on arrayed waveguide (AWG) or an alternate technology.

Although this invention has been illustrated by reference to specific embodiments, it will be apparent to those skilled in the art that various changes and modifications may be made which clearly fall within the scope of the invention. The invention is intended to be protected broadly within the spirit and scope of the appended claims.

WE CLAIM:

1. A method of demultiplexing an input optical signal having a plurality of wavelengths, said method comprising the steps of:

filtering the input optical signal using a polarization filter to produce a first subset of wavelengths at a first polarization and a second subset of wavelengths at a second polarization, wherein said polarization filter has a substantially flat transmission function in a wavelength region immediately surrounding each of a first plurality of transmission peaks and provides high isolation between first plurality of transmission peaks;

spatially separating said first and second subsets of wavelengths based on their polarizations; and

demultiplexing said first subset of wavelengths to produce at least a third subset and a fourth subset of wavelengths using a wavelength demultiplexing device having a transmission function having a second plurality of transmission peaks, wherein said first plurality of transmission peaks have substantially flatter transmissions and higher isolation than said second plurality of transmission peaks.

2. The method of claim 1 wherein said first subset of wavelengths includes every other wavelength in the input optical signal.

3. The method of claim 1 wherein said first subset of wavelengths includes a lower set of wavelengths from the input optical signal.

4. The method of claim 1 wherein the spacing of the wavelengths of said third subset of wavelengths is larger than the spacing of the wavelengths of the input optical signal by a factor of 2^N.

5. The method of claim 4 wherein N is equal to 2.

6. An apparatus for demultiplexing an input optical signal having multiple wavelengths, said apparatus comprising:

a polarization-based wavelength routing device having:

(a) a first output port;

(b) a second output port;

(c) a polarization filter having a first transmission function with a first plurality of transmission peaks forming a first subset of wavelengths and a second subset of wavelengths from the input optical signal;

(d) a polarization-dependent routing element routing said first subset of wavelengths to said first output port and routing said second subset of wavelengths to said second output port; and

a second wavelength routing device receiving said first subset of wavelengths and producing a third subset of wavelengths at a third output port and a fourth subset of wavelengths at a fourth output port, wherein said second wavelength routing device has a second transmission function with a second plurality of transmission peaks, wherein said first plurality of transmission peaks have substantially flatter peak transmissions and higher isolation than said second plurality of transmission peaks.

7. The apparatus of claim 6 wherein said first subset of wavelengths includes every other wavelength in the input optical signal.

8. The apparatus of claim 6 wherein said first subset of wavelengths includes a lower set of wavelengths from the input optical signal.

9. The apparatus of claim 6 wherein the spacing of the wavelengths of said third subset of wavelengths is larger than the spacing of the wavelengths of the input optical signal by a factor of 2^N.

10. The apparatus of claim 9 wherein N is equal to 2.

11. The apparatus of claim 6 wherein the bandwidth of said second plurality of transmission peaks is approximately twice the bandwidth of said first plurality of transmission peaks.

12. The apparatus of claim 6 wherein said second wavelength routing device comprises an arrayed waveguide device.

13. The apparatus of claim 6 wherein said second wavelength routing device comprises a fused biconical taper device.

14. The apparatus of claim 6 wherein said second wavelength routing device comprises a diffraction grating device.

15. The apparatus of claim 6 wherein said second wavelength routing device comprises a fiber Bragg grating device.

16. The apparatus of claim 6 wherein said second wavelength routing device comprises a thin-film interference filter.

17. The apparatus of claim 6 wherein said second wavelength routing device comprises a polarization-based wavelength routing device.

18. An apparatus for demultiplexing an input optical signal having multiple wavelengths, said apparatus comprising:

a polarization-based wavelength routing device having:

(a) a polarization separation and conversion stage converting the input optical signal to a plurality of polarized beams;

(b) a wavelength-dependent polarization filter selectively changing the polarization of components of said polarized beams based on their wavelength, said wavelength-dependent polarization filter having a first transmission function with a first plurality of transmission peaks forming a first subset of wavelengths and a second set of wavelengths;

(c) a polarization routing stage spatially separating said components containing said first subset of wavelengths from components containing said second subset of wavelengths based on their polarizations; and

(d) a polarization conversion and recombination stage combining said components containing said first subset of wavelengths; and

a second wavelength routing device receiving said first subset of wavelengths and outputting a third subset of wavelengths and a fourth subset of wavelengths, wherein said second wavelength routing device has a second transmission function having a second plurality of transmission peaks wherein said first plurality of transmission peaks have substantially flatter peak transmissivities and higher isolation than said second plurality of transmission peaks.

19. The apparatus of claim 18 wherein said first subset of wavelengths includes every other wavelength in the input optical signal.

20. The apparatus of claim 18 wherein said first subset of wavelengths includes a lower set of wavelengths from the input optical signal.

21. The apparatus of claim 18 wherein the spacing of the wavelengths of said third subset of wavelengths is larger than the spacing of the wavelengths of the input optical signal by a factor of 2^N.

22. The apparatus of claim 21 wherein N is equal to 2.

23. The apparatus of claim 18 wherein said wavelength-dependent polarization filter comprises a plurality of birefringent elements.

24. The apparatus of claim 18 wherein said wavelength-dependent polarization filter comprises a polarization fiber.

25. The apparatus of claim 18 wherein said wavelength-dependent polarization filter comprises a plurality of birefringent plates.

26. The apparatus of claim 25 wherein said plurality of birefringent plates comprise a crystalline material.

27. The apparatus of claim 26 wherein said crystalline material comprises calcite.

28. The apparatus of claim 18 wherein said polarization-based wavelength routing device further comprises a polarization mode dispersion compensator.

29. An apparatus for wavelength demultiplexing an optical signal having a plurality of wavelengths, said apparatus comprising:

a first stage wavelength routing device having an input port and a plurality of output ports, wherein said first stage wavelength routing device provides transmission functions associated with each path

from said input port to each of said output ports, and wherein each of said transmission functions is defined by a set of Fourier components providing a substantially flat transmission function from said input port to one of said output ports in a wavelength region immediately surrounding each of a first plurality of transmission peaks and high isolation between said first plurality of transmission peaks; and

a second stage wavelength routing device having a second stage input port connected to one of said first stage output ports, and a plurality of second stage output ports, wherein said second stage wavelength routing device provides transmission functions associated with each path from said second stage input port to each of said second stage output ports, and wherein each of said second stage transmission functions is defined by a set of Fourier components providing a transmission function from said second stage input port to one of said second stage output ports with a second plurality of transmission peaks, wherein said first set of Fourier components is selected such that said first stage transmission functions have substantially flatter peaks and substantially steeper roll-offs than said second stage transmission functions as defined by said second set of Fourier components.

30. The apparatus of claim 29 wherein said first stage wavelength routing device further comprises a polarization filter determining said first set of Fourier components.

31. The apparatus of claim 30 wherein said second set of Fourier components is determined by interferometric effects between propagating optical signals in said second stage wavelength routing device.

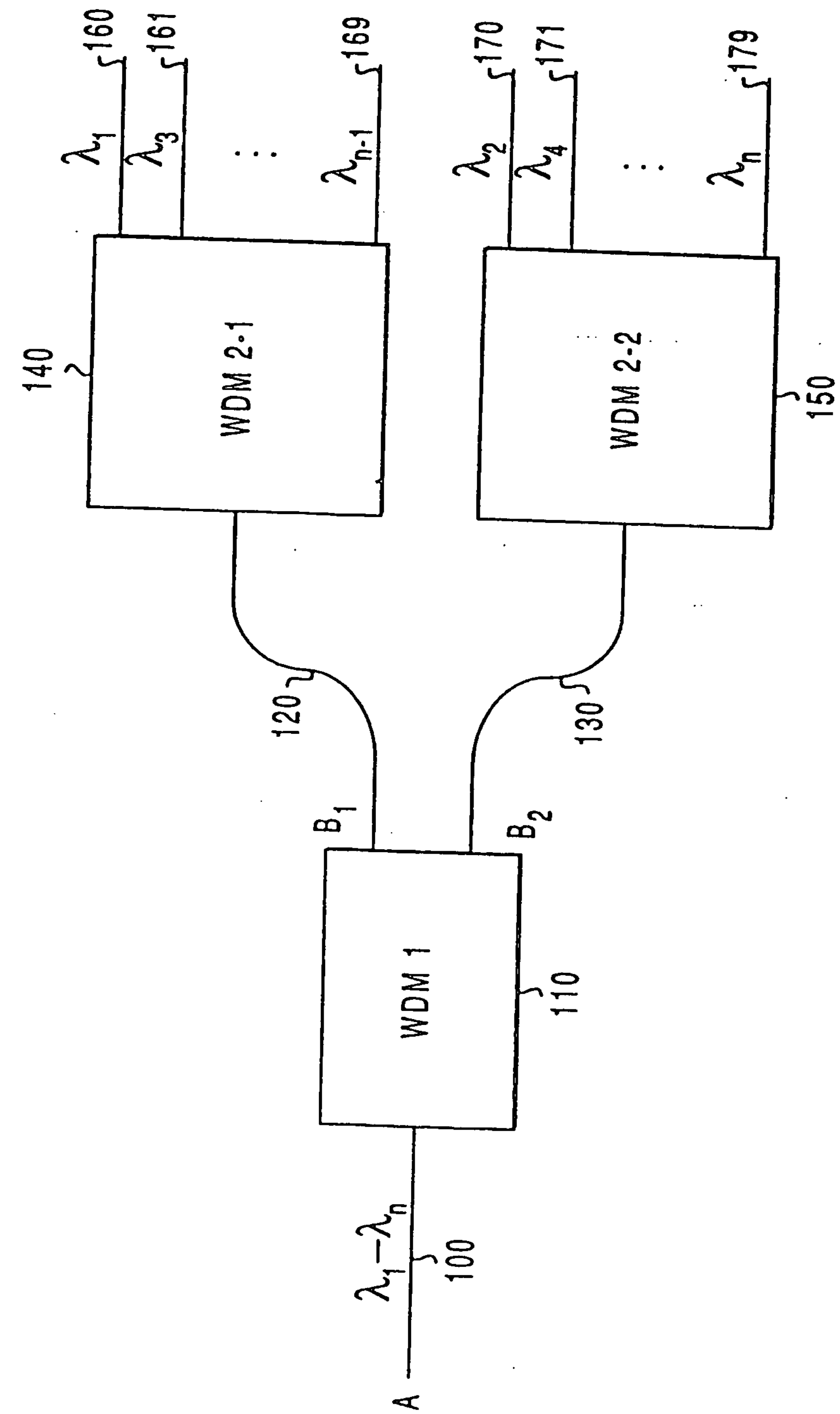

A
λ_1–λ_n
100
WDM 1
110
B_1
B_2
120
130
WDM 2-1
140
WDM 2-2
150
λ_1
λ_3
λ_{n-1}
λ_2
λ_4
λ_n
160
161
169
170
171
179

FIG. 1

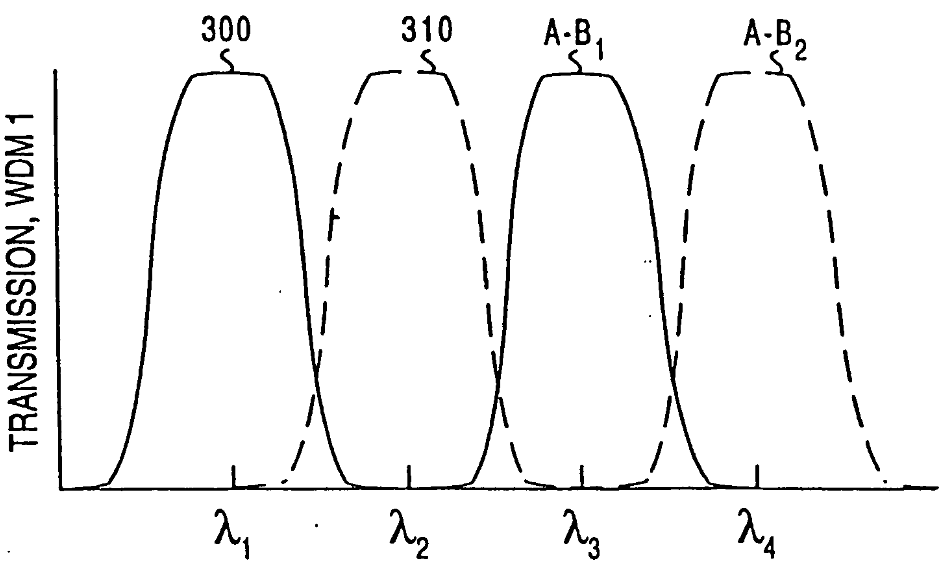
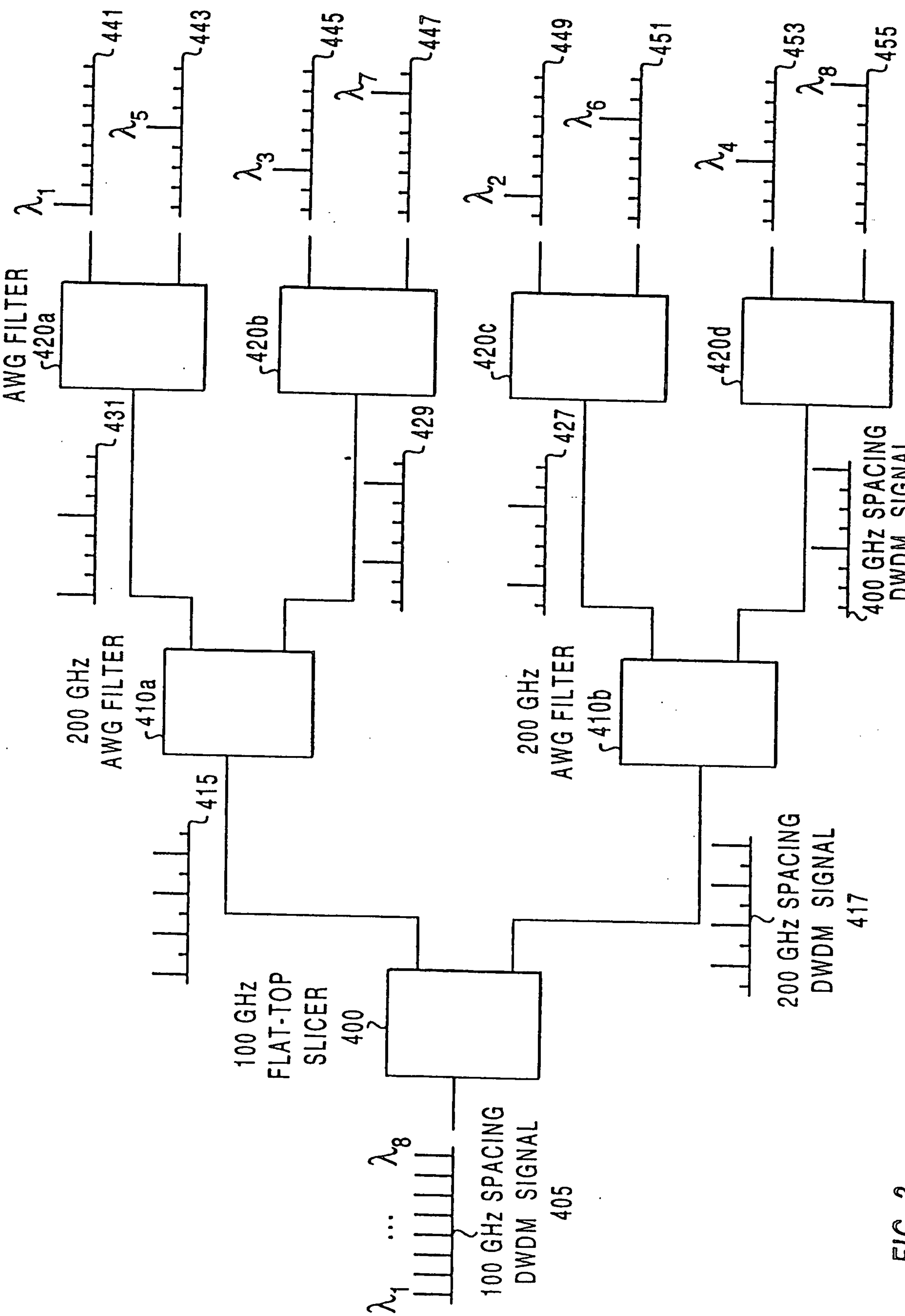

300
310
A-B_1
A-B_2
TRANSMISSION, WDM 1
λ_1
λ_2
λ_3
λ_4

FIG. 2



100 GHz SPACING DWDM SIGNAL 405
λ1 ... λ8
100 GHz FLAT-TOP SLICER 400
415
200 GHz AWG FILTER 410a
200 GHz AWG FILTER 410b
200 GHz SPACING DWDM SIGNAL 417
431
429
427
400 GHz SPACING DWDM SIGNAL 425
400 GHz AWG FILTER 420a
420b
420c
420d
λ1
λ5
λ3
λ7
λ2
λ6
λ4
λ8
441
443
445
447
449
451
453
455

FIG. 3

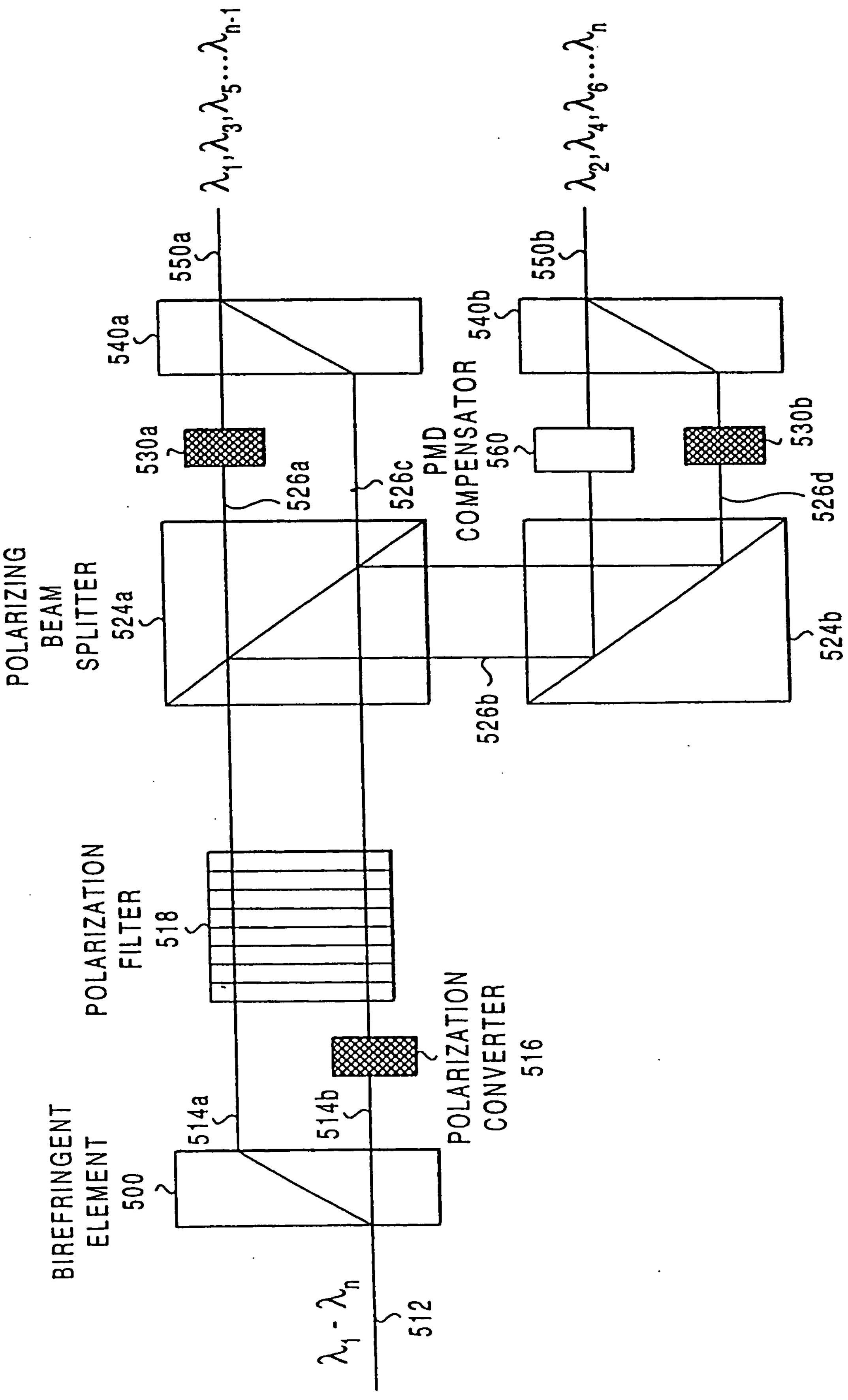

$\lambda_1,\lambda_3,\lambda_5\ldots\lambda_{n-1}$
$\lambda_2,\lambda_4,\lambda_6\ldots\lambda_n$
550a
550b
540a
540b
530a
530b
PMD COMPENSATOR 560
526a
526c
526d
POLARIZING BEAM SPLITTER 524a
524b
526b
POLARIZATION FILTER 518
POLARIZATION CONVERTER 516
BIREFRINGENT ELEMENT 500
514a
514b
$\lambda_1 - \lambda_n$
512

FIG. 4

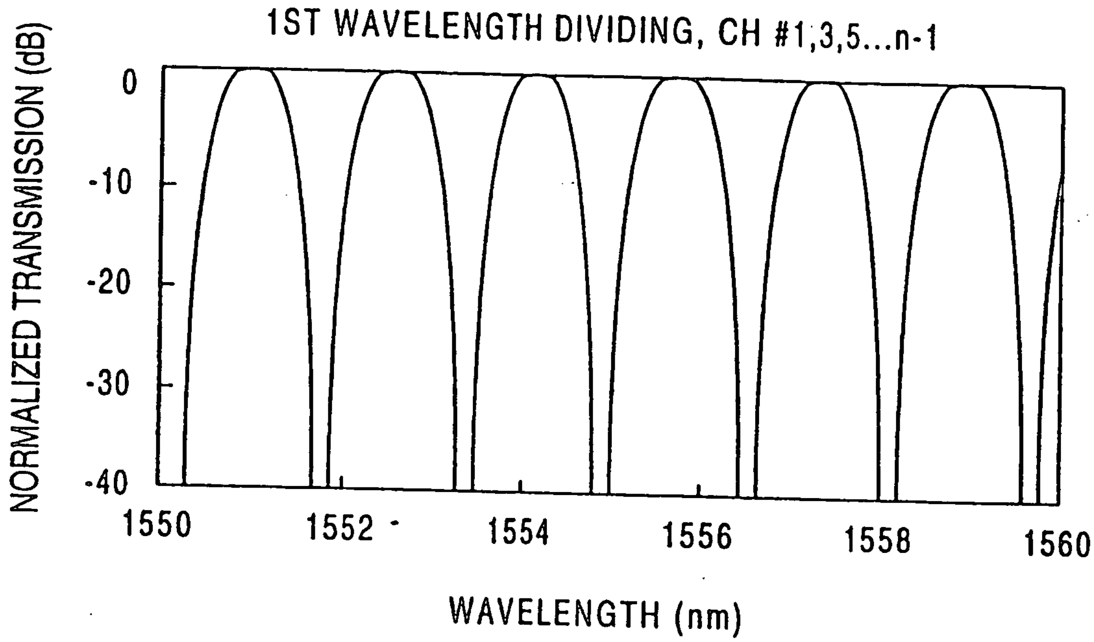

1ST WAVELENGTH DIVIDING, CH #1,3,5...n-1
NORMALIZED TRANSMISSION (dB)
0
-10
-20
-30
-40
1550
1552
1554
1556
1558
1560
WAVELENGTH (nm)

FIG. 5A

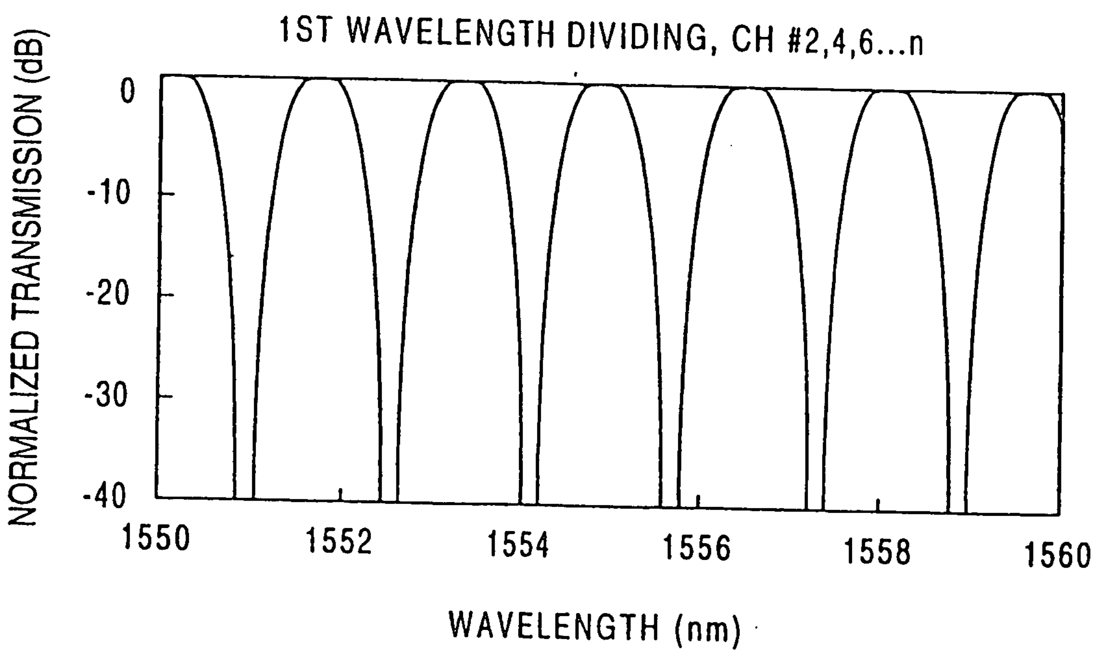

1ST WAVELENGTH DIVIDING, CH #2,4,6...n
NORMALIZED TRANSMISSION (dB)
0
-10
-20
-30
-40
1550
1552
1554
1556
1558
1560
WAVELENGTH (nm)

FIG. 5B

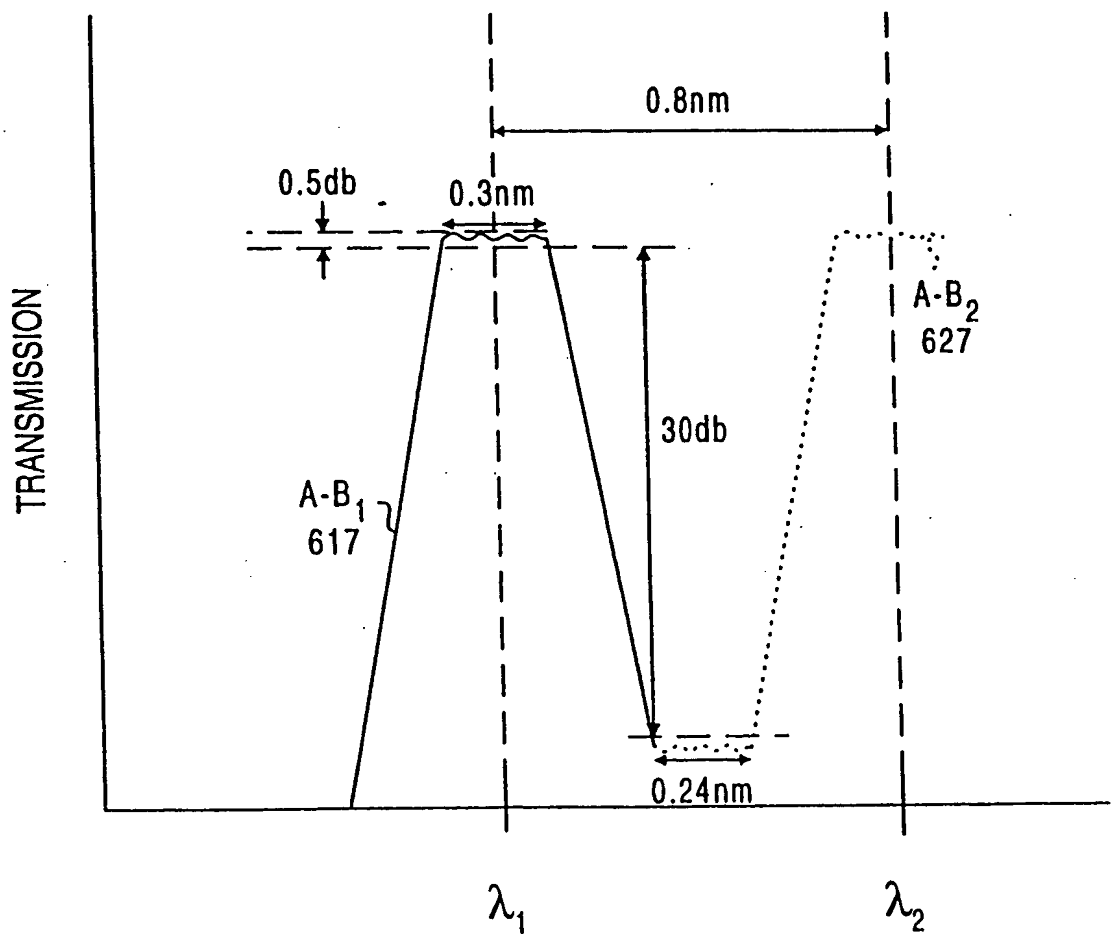


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/07390

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :H04J 14/02, 14/08
US CL :359/122, 124, 127
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 359/122, 124, 127-130

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,694,233 A (WU et al) 02 December 1997, see column 4, lines 53-55 and column 7, lines 24-27.	1-31
X,P	US 5,912,748 A (WU et al) 15 June 1999, see column 1, lines 61-63 and column 5, lines 6-8 and column 7, lines 1-3.	1-31
X	US 5,867,291 A (WU et al) 02 February 1999, see column 2, lines 26-31 and 45-48.	1-31

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 APRIL 2000	19 JUN 2000

Name and mailing address of the ISA/US	Authorized officer
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